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OF

ELECTRICAL ENGINEERS.

SPECIAL MEETING, SEPTEMBER 20, 1887.

SUBJECT:

On Electric Street Cars, with Special Reference to Methods of Gearing.

BY ANTHONY RECKENZAUN.

NEW YORK CITY:
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[Including October, November and December, 1888.]

The Geyer-Bristol Meter for Direct and Alternating Currents. [Illustrated.] Prof. William E. Geyer. The Abdank Magnetic Call and the Abdank Integraph. [Illustrated.] E. Abdank-Abakanowicz. No. 1, January, 1889. Six Years Practical Experience with the Edison Chemical Meter. (Illustrated.) W. J. Jenks. No. 2, February, 1889. Lightning Arresters and the Photographic Study of Self-Induction. (Illustrated.) E. G. Acheson. No. 3, March, 1889. A New System of Multiplex Telegraphy. (Illustrated.) Lieut. F. Jarvis Patten. Lightning Arresters and the Photographic Study of Self Induction. Notes by Jo. Stanford Brown and Chas. T. Child. Reply to the Notes of Messrs. Brown and Child by E. G. Acheson. No. 4, April, 1889. The Efficiency of Methods of Artificial Illumination. (Illustrated.) Edward L. Nichols. No. 5, May, 1889.

ANNOUNCEMENT.

BEGINNING with the present issue, the Transactions of each monthly meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS will be published in separate numbers. In order to facilitate their production the course hitherto adopted, of submitting the stenographer's notes or printer's proofs to the members, for the revision of their remarks, will be discontinued. The reports of the meetings will be carefully edited, and the monthly issue will be sent to all members and associates in good standing. Any corrections which are considered necessary may then be made in the margin of these pages and the pamphlet returned to the Secretary, who will forward a clean copy in its place. The type will be kept standing for one week, and all proposed corrections must be sent in within that time. The forms as revised will then be used for printing the yearly volume of *Transactions* in the usual manner. This course will permit the *Transactions* to be immediately circulated and in such shape that they may be accessible during the year. The rapid development of the various branches of electrical industry has made the delay in preparing a yearly volume strikingly apparent, and the officers are gratified to see that the support they are receiving from all quarters enables them to take this step, which they believe will meet with general approval. The additional expense will not greatly exceed that hitherto incurred, while the advantages to all, especially our distant members, whose interests should be carefully considered, will add materially to the value of membership.

The fourth volume of *Transactions*, covering the years 1886-87, is now going through the press and will be completed about the 1st of November.

Copies of the Rules of the Institute, lists of members, circulars, and blank applications will be furnished by addressing the Secretary,

RALPH W. POPE,
16 DEY ST., NEW YORK.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Special Meeting.

Held at 126 Fifth avenue, New York, September 20th, 1887.
The President, T. C. Martin, in the chair:

The President: It is with much pleasure that we resume our meetings for the coming season with a paper so important and unquestionably so interesting as that to which we are about to listen. The attendance this evening is large, and in that respect is very gratifying. We are a New York society, but on the other hand our membership extends all over the country. At the present time we have members in between thirty and forty States and territories of the Union and no fewer than ten countries of Europe, the West Indies, South America, and Canada. Under those circumstances it can be imagined that it is rather difficult to get all our members together when a paper is read here, no matter how important it may be.

The subject before us this evening is "Electric Street Cars, with special reference to methods of gearing." Mr. Reckenzaun, our distinguished guest, as you are all aware, has made a special study of this branch of the electric motor question, and it was through his genius and ability that the remarkable trip with an electric yacht was made across the English channel, the first of the kind on record. Not long after that trip Mr. Reckenzaun presented a paper before the London Society of Arts on a subject somewhat similar to that which he brings before us this evening, and so meritorious was it, and such was the interest that it excited, that the society felt justified in awarding Mr. Reckenzaun its silver medal. Mr. Reckenzaun leaves us to go to England to receive that medal. (Applause.)

In bringing this subject of electric cars before us this evening, it was thought possible that the paper should cover the whole subject, but after a little consultation Mr. Reckenzaun determined to restrict it more specifically to the subject of gearing, and I think you will all agree with me that there is no more important department of the subject of electric locomotion than that.

I now have the pleasure, gentlemen, of introducing to you Mr. Reckenzaun. (Applause.)

ON ELECTRIC STREET CARS, WITH SPECIAL REFERENCE TO METHODS OF GEARING.

BY A. RECKENZAUN, C. E.

Scarcely nine months have passed since your esteemed president, Mr. T. C. Martin, presented a paper on "Electric Street Cars" to the American Institute of Electrical Engineers. I have read this excellent paper with interest, and I have learned a great deal from it, as also from the discussion which followed. Mr. Martin compiled some very important statistics regarding the number of horse cars in actual use in the United States, and he computed them to number 25,000, for the propulsion of which no less than 120,000 horses are requisite.

These figures filled me with wonderment and surprise, and when I read further on, that over 20,000 of these noble animals are rendered useless every year with overwork in street railway service, I felt it to be the duty of every engineer, electrical or mechanical, to assist with every means in his power in the emancipation of the horse from such cruel service. The percentage of loss given in the paper referred to agrees closely with our European experience. We know that the natural life of a street car horse is reduced to about four years, although it never works more than four hours a day. It seems barbarous, therefore, to employ animals for such purposes; yet until recently no economical substitute could be found. Steam, compressed air, gas and spring motors have been tried and found inefficient. Improvements may be made in one or more of these, but at the present moment the field of enterprise is entirely open to the cable and to electricity. There are over 80 miles of cable roads in operation in the United States, more than half of which have been laid down within the last five years, and there are indications that further and rapid progress will be made with this mode of traction, particularly in hilly districts, where it is impossible to apply self-propelled cars, owing to the want of cohesion between the wheels and rails when the angle of repose is approached.

On ordinary streets with gradients of not more than five per cent., electric traction will doubtless be more economical and far more convenient than cables, for well-known reasons. Not only is the first cost of construction far cheaper than the cable and its conduit, but the efficiency of the electric system is much greater.

It is admitted that on cable tramways some 70 or 80 per cent. of the total available power is consumed in dragging the cable itself, leaving a maximum of 30 per cent. for moving the cars, whereas with electric transmission over 50 per cent. can be utilized, as will be seen by the following figures, which I have obtained from experiments on the electric railway at Frankfort in Germany. This line is worked by the overhead conductor system. Its total length is four and one-tenth miles, double track and grooved rails. The entire circuit of the conductor is eight and one-fourth miles long, and its electrical resistance was calculated to be 1.6 ohms.

Efficiency and Working Cost.

During the experiments referred to, two cars were propelled at a speed of seven and a half miles an hour; one of these cars had an electric motor, and the other was an ordinary car attached to the first, and the entire weight was ascertained to be 8.35 tons, including passengers. Electrical measurements were taken from the dynamo at the power station simultaneously with those on the car. The rails were in their usual dirty condition. When running on the level road the energy used on the cars was 3.87 horse-power, and on the generating dynamo 6.47, giving an efficiency of 59.82 per cent.; when traveling up a grade of 1 in 45, the motor gave eight horse-power and the dynamo 13.5, which again corresponds to 59 per cent. of the available electric energy. These measurements do not include the losses in the dynamo and motor, but it must be remembered that only two cars were on the road, whilst the capacity of the plant at the central station was sufficient for 14 cars. With 12 cars running under the ordinary circumstances of traffic, the steam engines were indicated, and this showed a maximum of 164 horse-power, consuming two and three-fourth tons of coal per day of 15 hours, or two and one half pounds per indicated H. P. per hour. Reduced to car miles, the weight of coal came to 7.5 pounds, which, at three dollars a ton, would cost one cent per mile run.

The Frankfort Electric Railway has carried over 3,000,000 passengers since its opening in April, 1884. The working expenses

in the year 1886 amounted to $24,904, including the following items:

Salaries of directors, superintendent, engineers, electricians, conductors, drivers, firemen, and laborers	$13,615
Repairs of roadway, rails, cars, machinery, and buildings	5,088
Fuel (coals and kindling wood.)	3,955
Oil and waste	831
Lighting and heating of buildings, lighting of cars and streets	1,415
	$24,904

The rolling stock consisted of 14 cars, all of which were used on Sundays and holidays, but only eight cars were usually running on week days. If we take an average of 10 cars, then the entire expenses would amount to $6.82 per car per day, but not more than one-third of this, or $2.27, can be reckoned for the item of traction, which should only include wages of engineers, electricians, firemen, cost of coals, oil, and repairs to machinery.

There are about a dozen electric railways in successful operation in Europe, some more extensive than the one I have just described, some smaller; but this one in Frankfort is worked at a greater expense than any of the others I know of; it has been in continuous use for nearly three and a half years, and I thought that by giving you detailed and exact figures of *one* line, I would serve your purpose better than by attempting to crowd a few generalities of all our electric tramways into the small compass of a short paper. You can take this as a safe standard of comparison with other systems of street car traction.

It will be observed, with justice, that the dynamos and motors of the Frankfort line, which was projected more than four years ago, do not yield as high an efficiency as more recent machines. This would leave us another margin. It is well to have a margin in all our estimates, for there is nothing that retards the progress of a novel enterprise more than exaggeration of facts, or statements which cannot be fully borne out in practice.

Some people are apt to base their calculations and estimates upon theoretical conditions. We should never assume perfection in the case of street railway tracks, but on the contrary we ought to adapt ourselves to the roughest of the rough in order to succeed.

Tractive Force and Mechanical Resistances.

We know from experience that street rails which are exposed to dirt, grit, stones and the like, offer a resistance of at least 20 pounds per ton with the wheels in motion. Taking the loaded

car at six tons, and the speed at six miles an hour, we have to exert 1.92 horse-power at the driving wheels, neglecting friction of gearing and losses in the electric motors. On narrow grooved rails, as used in England, we allow a tractive force of from 25 to 30 pounds per ton. These high resistances are readily accounted for when it is considered that the flanges of wheels frequently take a bearing on the dirt in the grooves; at the same time the wheel tires may roll on the surface of the rails, when a regular grinding action is produced. Furthermore, it occurs frequently that one wheel is running on its proper bearing surface, whilst the other, belonging to the same axle, has its flange touching the bottom of the groove, when by virtue of different circumferential velocities, additional friction is introduced. Sometimes the rails are a little out of gauge. All these points increase the tractive force requisite with grooved rails. Here in America you have few if any such rails, consequently the facilities are superior; but your rails are not so strong as those used in England and on the continent of Europe, and the foundations are less substantial. The joints are also somewhat irregular, and these faults render the motion of a car very unsteady. A ride on some of the roads in Philadelphia reminds one of a voyage on the ocean when the sea is a little rough. Then you crowd very often 70 passengers into a car which is supposed to hold about 30. All these circumstances compel us to provide plenty of power in order that every obstacle can be overcome.

The force necessary for starting a car is of course much greater than the force required for maintaining a uniform speed, and experiments show that this initial effort amounts to three times and even four times the tractive force of the car in motion. In dry weather, on curves of 50 feet radius, the resistance to traction is doubled, and on those of 35 feet radius trebled; but when the rails are wet this resistance, due to curvature, is considerably reduced. With a short wheel base, or, better still, with small trucks or radiating axles, the motion on curved rails is very much easier.

Gradients.

The effect of gradients is a matter of simple calculation, and it must be provided for in designing and constructing a motor. We have calculated above, that the minimum effective power for a six ton car running at six miles an hour on the level is nearly two horse-power, exclusive of gear friction or any other waste. If we have to overcome a gradient of one per cent., for instance, the resistance due to gravity will be 22.4 pounds for each ton, or

134.4 pounds for the loaded car. Therefore we shall require about four horse-power to pull this car up a grade of 1 in 100. With a two per cent. grade we must have about three times the power used on level roads, and roughly speaking each per cent. of grade involves as much energy as the propulsion of a given weight over a horizontal road, if the speed is to be kept constant. On steep grades, however, it is customary to run a little slower, whereby some of the energy is saved, but for a car of the above weight, if it has to overcome grades of four per cent. it will not be safe to have less than eight horse-power available upon the driving axles. In addition to this the motor has to supply the power which is unavoidably wasted in the gearing used for transmitting motion from the armature shaft to the car axle. An ordinary street car wheel of 30 inch diameter has to revolve at least 77 times in the minute, in order to traverse a distance of seven miles an hour. Up to the present time no one has succeeded in constructing an electric motor of reasonable dimensions, weight and efficiency to work at such a low speed. Most of the existing motors revolve at from six to twelve times the above velocity ratio, therefore it became necessary to introduce speed-reducing appliances between the motor and the driving axles.

Gearing.

The problem of devising suitable gearing for street cars carrying their own motor has been and is still one of the greatest importance, and I propose now to offer a few remarks with reference to this subject, by citing some examples which came under my own observation. The conditions to be satisfied are by no means simple, and it is somewhat difficult to arrange them in their order of merit. Most engineers endeavor to retain the recognized dimensions of street cars, because great deviations therefrom involve many inconveniences, and it is wise to adhere as much as possible to the rules which have been established by custom, convenience, and general utility. The fact that most of the street cars in all parts of the world are similar in shape, indicates forcibly that a particular pattern satisfies the demand. When taking that popular pattern of car and adapting to it our electrical and mechanical apparatus, we find that the space at our disposal underneath the floor and between the axles is meagre and extremely limited. Within this small compass we have to fix the gearing which has to give the highest possible return of a given power; it has to be strong, durable, yet light in weight; noise and vibration have to be carefully avoided; the mechanism must be

simple, certain in its action, protected from wet and dirt, and finally, of reasonable cost. How to combine all these virtues has been the study of every engineer who has made electrical traction his serious study.

Steel Spiral Cords.

In regard to my own observations, one of the prettiest kinds of gearing in actual use is that on one of the cars of the Berlin Lichterfeld Electric Tramway which was constructed six and a half years ago by Messrs. Siemens and Halske. This car has a capacity for 24 passengers; it weighs when empty 3.2 tons and makes a speed of 12 miles an hour. The electric motor is fastened under the floor in the center of the car, having its shaft parallel to the axles. On the motor shaft is a small cast-iron pulley, which has 27 V-grooves on its rim, and within these grooves work an equal number of spiral wire cords, which transmit the motion to both axles of the four-wheeled car. The axles carry the large pulleys, one of which has 13 V-grooves on its circumference, and the other 14 grooves corresponding with those on the pulley on the motor shaft. The wheel base is five feet nine inches, consequently there is only a distance of two feet ten and a half inches between the centers of the connected pulleys.

The cords are made of a pair of steel wires wound closely upon a mandrel of about one-eighth of an inch in diameter, and when this mandrel is withdrawn there remains a stiff, yet flexible spiral, whose external diameter is scarcely $\frac{1}{11}$ of an inch. When cut to the proper length these cords are stretched over the grooves and connected at the ends by means of steel eyes and a steel link. Experiments made with this gear showed that eight spiral cords suffice for transmitting the power to the axles when the car was full of passengers, and as there are actually 27 cords the margin of safety was deemed more than sufficient. It is a pleasure to ride on this car; there is no noise or vibration, and I was told that the spirals last a long time if carefully adjusted; but this method of transmission is not sufficiently positive to warrant its application on steep grades. On this line there is no grade of over one per cent. rise.

Chain Gearing.

The second car on the Lichterfeld tramway, which, by the way, must be regarded as the oldest line in the world as far as continuous successful operation is concerned, has chain gearing. The motor shaft is provided with a small toothed wheel, and one of the

axles carries a large wheel with teeth to correspond to the gaps in the pitch chain links. This mode of transmission causes some noise and vibration, and this car runs slower than the other with the same amount of energy. This is accounted for by the greater friction on the surface of the teeth, as well as by the bending and unbending of the link joints; there is, besides, a constant probability of the comparatively heavy chain being thrown off tangentially by centrifugal force. But this kind of gearing furnishes an absolute or positive motion, which cannot be relied on by methods depending upon frictional adhesion alone.

Some four years ago I applied two pitch chains, four toothed wheels and countershaft for propelling a heavy storage battery car in London. The chains were of steel and substantially made; the wheels of phosphor bronze correctly shaped. I found that the chain on the fast-running, first-motion shaft, rattled considerably. This chain stretched a little, when the links began to ride upon the points of the teeth, and eventually broke the teeth of the small wheel on the armature shaft. Previous to that I employed some other gear, which will be mentioned shortly.

Mr. Trail, the manager of the Portrush Electric Railway in Ireland, has been more fortunate than I with chain gear, but he is not perfectly satisfied, and he is now experimenting with something else. Pitch chains are also used on the Bessbrook-Newry Electric Railway and on the Ryde Pier cars. Mr. Holroyd Smith adopted this mode of transmission on the first cars at Blackpool, in England, but he has since changed it to worm gearing, with which he is better satisfied.

Conical Disks and Chains.

About five years ago I had the idea that it might be advantageous to vary the speed of a car mechanically without interfering with the motor or even the supply circuit. I took out a patent for this in 1882, and applied it to the propulsion of a large street car. The motor was carried by a frame supported upon the axles by bearings and springs, to counteract the effects of vibration. By this arrangement the whole apparatus was rendered independent of the car body, and it could be easily detached. The speed pulleys consisted of conical disks, which, when placed face to face on a shaft, each pair formed between them a grooved pulley, and by shifting these disks on the shaft towards or from each other, the said groove could be made wider or narrower, as desired. Two pairs of disks on different shafts were connected by means of a chain, the links of which were surrounded by wedge-shaped

pieces of leather. The cross section of this chain band was thus shaped in order to fit into the V-grooves offered by the cones. When the said disks were pressed closely together, then the band assumed a position near the circumference of the disks, but when the latter were separated, then the groove widened, the band changed its position and ran on some portion of the conical surfaces nearer the center of the pulley. Thus the effective or acting diameter of the first motion pulley was varied at will by pressure, and the cones on the second motion shaft followed suit automatically, because the length of the band was constant, and the second pair of cones was pressed together by a strong spring. This arrangement looked very nice, but its efficiency was low; there was a great waste of power through friction, and we finally abandoned it. It worked silently; it was strong and took up little room. The band slipped often when the car was starting or mounting an incline.

Straps and Pulleys.

Mr. Volk, of Brighton, England, employs leather link belts with great success, for transmitting the power of the motor to the car axle. This railway has been in operation since August, 1883. Mr. Volk tried first, single leather belts, but they broke every day or two; then he used double belts with little better results, and some three years ago he adopted the leather link belt, which has given entire satisfaction. I have seen one of the latter which has driven a car over 50,000 miles and it was not worn out yet. These belts stretch when first put on, the bearings of the countershaft are therefore made adjustable by means of a slide whereby the slack may readily be taken up. When starting the car the belts slip a little, but this is not considered a disadvantage. There are no curves on the Brighton line, and I often wondered whether this method of gearing would satisfy the terrible pull on the very sharp curves which occur on some street railways.

Mr. Van Depoele has given a high testimony in favor of link belts of a special construction after using them for a considerable time, and running them at a great velocity. Like Mr Volk, he attaches the motor to the car body in order to give it the benefit of the existing flexibility of the car springs. Mr. Van Depoele's link belts, I understand, are made of steel, with special bearing surfaces; they have been used on a line of his construction at Windsor, in Canada; at Scranton, Pa., he employs spur gearing.

Spur Gearing.

There exists a variety of opinions on the subject of toothed wheels in connection with electric motors, and each opinion seems based upon actual experience. I have seen spur gearing used on electric cars in Europe and in this country, and I give you freely all I know about it. The first I saw was on the Moedling line, near Vienna in Austria. The noise created there was not very great, but there was occasionally some trouble due to the untimely deterioration of the teeth. This was especially remarked by the manager of the Frankfort Electric Railway in Germany, which is constructed on precisely the same principles, with the difference that the former runs through a country district where there is much less traffic, and the rails are laid on the tops of transverse sleepers like a steam railroad; there is less dust and mud to contend with. Between Frankfort and Offenbach, on the other hand, the rails are laid through populated streets, whereby all the disadvantages of city traffic are brought into play. The gearing of the cars on this line is very noisy and it wears out quickly. The train of wheels consists of a pinion on the motor shaft having 17 teeth, which gears into a spur wheel of 56 teeth keyed upon a countershaft. On this countershaft is a pinion of 26 teeth and this drives a spur wheel of 52 teeth, fastened to the car axle. The velocity ratio, therefore, is as 1 to 6.6, between the motor spindle and the driven axle. The armature makes about 550 revolutions when the car travels at the rate of seven and a half miles an hour. The pinions are made of hard gun metal, and they wear out in about a month. I have seen a number of rejected pinions the teeth of which were ground into the shape of a fine wedge. The spur wheels are of cast steel and they last about ten months when in continuous service. I was surprised to see these; and what with the noise, the excessive weight and other drawbacks, it made me more than ever prejudiced against such a mode of mechanical transmission on street cars. My views on this point have, however, been somewhat modified since I have been in this country. I had the privilege of being invited to assist Mr. W. Wharton, Jr., of Philadelphia, in fitting up an electric street car. There we used a set of spur gearing which was supplied by the Sprague Company. In this case the motor shaft, which runs at from 500 to 600 revolutions a minute, carries two steel pinions, one at each end of the shaft, and these pinions gear direct into two cast-iron spur wheels upon the driving axle, without any intermediate wheels. The motor is partly suspended on the axle and partly on the body

of the car. We have run several hundred miles with this car under all conditions of load, gradients, and weather, on some of the roughest tracks in Philadelphia, but up to this moment not a single hitch has occurred. The gearing is practically noiseless, it is efficient and strong, and I see comparatively little indication of wear. The teeth are beautifully shaped, therefore somewhat expensive, but if they last long enough, and if they do not rattle when partially worn, this expense can be ignored. This car contains, besides its usual weight, about 3,200 pounds of storage batteries; it has to mount grades of 5 per cent., and run on curves of 35 and even 25 feet radius, which means very hard work.

Friction Gear.

There is something quite fascinating in friction gear; it offers the advantages of simplicity, noiselessness, and theoretically a high efficiency; but as regards certainty of action and durability, it occupies a low position in the scale of appliances for the transmission of power. The late Professor Fleeming Jenkin devised an apparatus a few years ago which he called "nest gearing," and of which great things were expected, and indeed it was regarded as the most perfect frictional gear ever invented.

Professor Jenkin arranged several rollers within a ring; these rollers were in contact with a central friction wheel which was attached to the motor, and the outer ring was connected to the driven object. It is well known that in a pair of friction wheels when running together, the contact surfaces are exceedingly small, the pressure must be great, and consequently there is a rapid destruction of the said contact surfaces. Now, by placing a number of rollers within a ring, not only are the contacts multiplied, but there is a perfectly balanced pressure upon all the working parts. This kind of gearing, made of the best materials and of the finest workmanship, has been applied to the telpher line at Glynde. Its efficiency was tested and found to be somewhere near 95 per cent. In the case of telpher lines the motor and its attachments is well out of reach, suspended on tall posts, therefore dust and dirt can be absolutely excluded. The energy transmitted between the electric motor and the driving wheels averaged only 1.5 horse-power, and yet with all these advantages and the great care exercised in its construction and use, this gearing refused to act after a comparatively short space of time. The experiments were watched with intense interest by all who made mechanical science their profession, and especially by those who were seeking effective means of transmitting motion from electric motors. After a

number of exhaustive tests, apparent improvements and modifications, the inventors of this nest gearing pronounced it a failure, and finally resorted to chains and cog-wheels. This fact, established after prolonged and most persistent efforts on the part of a number of the smartest mechanicians, should be a warning to all the advocates of friction gear for street car propulsion.

Worm Gearing.

Dissatisfied with the results of my early experiments I resolved to give worm gearing a trial. I collected all the data I could find in text books and from other people's experience. All the different authorities agreed on one point, and that was the efficiency, or rather the want of efficiency in worm gearing. According to various statements the *loss* with this mode of transmission was put down at from 33 to 75 per cent. This seemed to me a terrible waste of power; I was then, as now, engaged in the problem of utilizing storage batteries for street car propulsion. Storage batteries were at that time in disrepute generally, and as for putting these cumbersome things upon a car, the very idea of it was ridiculed by conservative-minded men. Certain would-be experts published their views on this subject, and they endeavored to prove mathematically that the battery could scarcely hold sufficient energy to propel its own weight, and that more than 50 per cent. of the power given by the charging dynamos was lost in the process of transformation. If they had known at the time that I proposed to introduce another energy-consuming apparatus in the form of worm gearing they would have declared me a lunatic. There were, however, quite a number of extenuating circumstances which encouraged me to pursue this question. I knew, from experience, that the storage battery, if properly constructed and used, could return more than 70 per cent. of the energy expended upon it; I knew also that a certain type of cell could propel several times its own weight at a speed greater than that of a horse car.

With regard to worm gearing I found that this method of transmission was used for hoists and for actuating machine tools, and that in some cases it has been working for twenty years without requiring any expensive repairs. During all my researches I failed to discover any reliable data on the construction and use of a worm which had such a steep thread that the worm-wheel could cause it to revolve. I did not come across any publication with figures to show the efficiency of gearing where the worm-shaft revolved at a very high velocity whilst transmitting considerable power. Just

at that time the valuable researches of Professors Thurston and Kimball and Mr. Beauchamp Tower, on the subject of friction and lubrication, were published, and these revealed the fact that all the long-established laws on friction were entirely wrong. The experiments of these scientists proves conclusively that the coefficient of friction varied with the velocity, and that it decreased up to certain limits, with an increase of speed between lubricated surfaces.

Furthermore, it has been demonstrated that the coefficient of friction between lubricated bearings is not .1 or .2, as so frequently stated in text books, but .003 and less, and that even with moderately bad lubrication it amounted to only .01. All these, and other considerations encouraged me in the belief that there is a fruitful field for further investigation, and I designed a set of worm gear of the following dimensions: Steel worm, turned and polished, 6 inches in diameter, 6 inches long, treble thread of 2 inches pitch; worm wheel of phosphor bronze, trimmed teeth, $15\frac{9}{32}$ inches diameter, $3\frac{1}{2}$ inch face, 24 teeth. Ratio of gear, 8 to 1. The worm was fitted to the spindle of an electric motor, and the worm wheel attached to the axle of a street car, which was supported on a frame with bearings to keep the wheels off the ground. When running empty, with the worm out of gear, the motor took 6 amperes of current, and when put in gear, but without any other load, 7.75 amperes were used to drive the apparatus at the same speed. Prony brakes were then applied to both the motor shaft and the car axle, and the power was measured on each at a given E.M.F., current, and speed. The efficiency of the gearing was calculated by dividing the horse-power given off on the axle by that measured on the worm shaft, and we found that the useful effect increased with the speed, viz.: at 300 revolutions of the worm it gave 80 per cent.; at 530 revolutions, 81.1 per cent.; at 676 revolutions, 85.1 per cent., and finally at 770 revolutions, 87 per cent. These results were then compared with the electrical energy supplied to the motor in each experiment and they were found to correspond very closely, after the usual electrical losses in the motor itself were deducted. The mechanical horse-power was thus checked by the electrical horse-power, and at last I applied the well-known formulæ for the efficiency of worm gear, which is given in every book on mechanical engineering.

$$\xi = \frac{\cot\ \theta}{\cot(\theta - \Phi)} = \frac{1 - \mu\dfrac{p}{2\pi r}}{1 + \mu\dfrac{2\pi r}{p}}$$

Where θ is the angle of the worm thread,
μ the coefficient of friction,
r the radius of the worm, and
Φ the angle of repose between metal and metal
ξ gives the efficiency of the pair.

If the coefficient of friction is taken at .015, then the efficiency must be 87.5 per cent.

By means of the above tests and the formula we can find the coefficient of friction for the various speeds.

When this apparatus was attached to the car, I found that it required less current to propel it than it did previously with the chain gear, therefore I adopted worm gear ever since. Mr. Holroyd Smith tried it recently on his cars, as already stated, and he told the meeting of the Society of Arts, in April last, that he "found it the most effective mode of transmitting the power from the motor spindle to the axle, taking all points into consideration."

With these remarks closes a short and incomplete chapter on gearing. There are other kinds of gearing which I have not touched upon. I cannot do better than to leave the subject in the able hands of members present, who, I hope, will supplement, criticize and amend the observations herein set forth, and thereby add to the general knowledge of one of the most important topics of the day. We are continually advancing; every hour marks a step forward in the direction of success. The grand general principles of the electrical transmission of energy are now well understood, but there are yet many other ways of adding to the sum of human knowledge, as for example in following up the details of construction, every one of which will add in some measure to the final triumph. Even by relating our mistakes and failures we serve a good purpose. "There are," said Professor Sylvanus Thompson, "half-forgotten observations, unconnected, unexplained, and often exceptional in character, every one of which has a significance of its own—residual phenomena, every one of which is, to the scientific man, of a value beyond price. He who investigates them patiently may find the clue to their meaning and reap a rich reward from them. They are the finger-posts in the high road of discovery."

DISCUSSION.

THE PRESIDENT: Gentlemen, the valuable paper to which you have listened is now open for discussion. It is natural under the circumstances that as we have Mr. Reckenzaun with us but once, and as he is about leaving for Europe, that we should, so to speak, put him in the witness box, and puzzle, perplex and annoy him with questions. In that way I have no doubt we would greatly add to our stock of information on the subject. But I know Mr. Reckenzaun would, if anything, prefer a discussion rather than a series of interrogations, and I think that on the matter presented before us to-night, and with half the gentlemen in attendance directly interested in street railways as run by electricity, the subject should not lack ventilation, and I venture to believe that should any gentlemen desire to discuss some of these points with Mr. Reckenzaun he will find a foeman worthy of his steel.

THE SECRETARY: There is one point in connection with the worm gearing which I have heard referred to before, and I presume, as Mr. Reckenzaun's name was mentioned in connection with it, he can give us further details, and that is the matter of lubrication. I understood when this question was up before, that in his use of worm gearing the worm was run in oil, and if so, I would be pleased to hear some further details.

MR. RECKENZAUN (making a sketch showing the worm and the worm wheel enclosed in a case): The first bearings are generally made of several collars. There is a tin box completely around the gearing, having a hole for the shaft, with a very tight stuffing box. The whole gearing is thus closed almost air-tight. If you place ordinary lubricators above, just to start the thing, and if you place two or three inches of oil at the bottom of this tank you will find that there is a perfect, continuous, automatic lubrication. The teeth of the worm wheel will lift up just sufficient oil to lubricate the worm, and there will be sufficient oil always running around—flying about inside the case—to keep the whole thing well lubricated. There is hardly any waste of oil going on, through leakage at the shaft, or here at these points. Thus you have a perfect lubrication that cannot fail at all. I believe this is the only question that Mr. Pope asked with reference to the lubrication. Of course you can use any lubricant you wish. Some lubricants are far more efficient than others. Naturally we should use the most efficient lubricant we can get in the market. With regard to the friction surface of the worm wheel,

I have mentioned that that is made of phosphor-bronze and the worm is made of steel. These two metals have a very low co-efficient of friction between them. The worm is, moreover, turned out of a solid piece of steel and perfectly polished. The phosphor-bronze wheel is a toothed gear, the teeth thoroughly trimmed, and also polished inside. They have, therefore, a perfect wearing surface to start with. The worm gearing works for a considerable length of time without any appreciable wear on the teeth at all. I think a perfectly constructed worm gear ought to run twenty years without renewal if properly lubricated. The prejudices against the worm gearing will soon wear away. Up to the present time it has been constructed on anything but scientific principles. The teeth were at a very small angle. The material used for the worm was frequently cast-iron. The worm wheel was sometimes made also of cast-iron. Sometimes they made wrought-iron worms and cast-iron wheels.

MR. WETZLER: I would like to ask Mr. Reckenzaun if he has ever tried to use a worm which, instead of being cut cylindrically, has been cut so as to conform to the radius of the wheel into which it geared.

MR. MAILLOUX: The hour-glass form.

MR. WETZLER: Yes, the hour-glass form, as Mr. Mailloux says.

MR. RECKENZAUN: All the worm gearing I have constructed has been made on the plan of cutting it out cylindrically.

MR. WETZLER: The worm having the hour-glass shape is said to be more efficient, according to Prof. Thurston's experience.

MR. MAILLOUX: I would like to add by way of information, that this form of worm was the very first that was used. If I mistake not, it was the celebrated mechanician or engineer Hindley, who first devised the worm, and it was in that form that he gave it to the world—the hour-glass form as he called it. The shape of the teeth is varied as they go toward the end near which they point inwardly in a radial form, as Mr. Wetzler has said.

With regard to the worm, I have watched with interest the evolution, so to speak, of means of transmission from the motor axle to the car axle, and I am very well prepared to agree with our friend Mr. Reckenzaun, that it is undoubtedly one of the most important problems that we have to deal with to-day. In fact, I may say that it is the only remaining unknown quantity in the problem of electrical traction. The problem of designing and constructing electric motors has advanced by the assistance of workers, mathematicians and others until it is to-day a question of engineering, you might say, almost purely; but the manner in

which we should dispose of the energy in order to render it available for moving the car, is not, unfortunately, so well taken care of; and the very fact that we see so many diversified attempts to meet the severe requirements which Mr. Reckenzaun has so well placed before us, shows that a satisfactory solution—at least one that is satisfactory to everybody—has not yet been reached. Some are very much predisposed in favor of belting, others in favor of gearing, friction appliances, etc. Now there is going to be, I believe, a certain amount of competition between different forms of gearing, leaving aside for the present other methods, such as belting, etc. There is to be some divergence of opinion for some time to come, as to which is the best form of gearing. Experiments have been made by very able persons on the subject, and so far, nearly all of them concur in ascribing to the worm a much lower efficiency than to the spur form of gearing. I have in mind some experiments which were made under the auspices of Messrs. Sellers, of Philadelphia, in which they sought to go thoroughly to the bottom of the problem, and to arrive at some conclusion as to the relative efficiencies of the various forms of gearing. The results attained showed first that the efficiency did increase with the speed, as Mr. Reckenzaun has stated, but that this efficiency did not increase always with the speed; that it reached a certain maximum just as you would expect; and a very curious circumstance was that the forms giving the highest efficiencies were those two ordinary direct spur gearings in which the shafts are parallel with each other. Starting from that they made experiments in which the angle of the two shafts was gradually increased so that there was, so to speak, a gradual transition from the form in which the two shafts were parallel to that in which the two shafts were at right angles to each other, as in the worm gear. We may say, in fact, that worm gearing and spur gearing will be the two extremes of a certain scale of transition, intermediate between the two extremes being placed the so-called helical gearing in which the teeth are placed at an angle in spirals. The results obtained by the Messrs. Sellers, or the persons who carried on the experiments for them, showed that the nearer they approached the form of the worm, the lower was the efficiency. I have not in mind the figures of the efficiencies, but the experimenters themselves rather left us in doubt as to the value of their results, by referring to very many circumstances which, in their opinion, would vitiate some of the results obtained, and there were certain conditions of the operation of their apparatus, etc., which they were not exactly satisfied with. I must say for myself that I

have always looked upon the worm with more or less suspicion. While I was not prejudiced against it, particularly after seeing the beautiful results obtained with it by Mr. Reckenzaun, in England, yet at the same time I felt that it was to be taken under proba. tion, so to speak. There are some disadvantages, I think, which are connected with the use of the worm, and one of them which occurs to my mind just now is the difficulty in running down hill when the worm is fastened to the motor shaft. When an electrically propelled car runs down a grade it is usually found possible to shut off the current in a great many instances, and this, of course, results in a certain saving of energy. Now, unless the pitch of the thread was properly calculated, it seems to me that it would be somewhat difficult for a car to move down hill with ease, because of the well-known difficulty of moving such an arrangement backward. It is very well known that a thread can be used to turn a toothed wheel, but it is very hard to turn the thread by means of the toothed wheel. I understand that Mr. Reckenzaun has met this difficulty, though I do not know whether he still considers it one of the things to be remedied, or whether he deems the remedy that he has proposed sufficient.

Now, turning back to the other form of transition, namely, the pinion, which I have said is likely to be one of the opponents or rivals of the worm system, I have in mind some form of that kind which I saw in use a year or so ago, which it seemed to me was very well adapted for the purpose that it had to serve. Recognizing the fact, of course, of a great tendency to wear, in the pinion or in the gear wheel, and also the great tendency to the production of noise, a special form of pinion had been devised. This was made by taking a number of thicknesses of raw-hide or leather—I think it was raw-hide—and closely packing them and threading them, so to speak, on the shaft, with nuts to hold them in place, then cutting inside a thread so as to make a pinion of these thicknesses of raw-hide. The gear wheel, I understand, was of phosphor-bronze—it had that appearance. I made some experiments with that system at Providence, at the works of the Rhode Island Locomotive Works. I think the name of the system was the Bentley-Knight. I found the working of it to be satisfactory. It was entirely noiseless, and the only doubt that there was in my mind as to its success was the question of durabilty of the pinion. I have no doubt that if there is any wear it must necessarily come on the pinion, that being the softer substance of the two; but I have no data by which I could arrive at the comparative durability of the raw-hide pinion.

With regard to the chain, I may add a word which might be interesting by way of information. My experience with it goes to show that the loss from its use is not nearly so great as might at first be supposed. In that respect the pinion is placed in very nearly the same position that the worm gearing is. In other words, it depends largely on who is using it, and how it is used. Mr. Reckenzaun has obtained excellent results—nobody will deny that—from that worm gearing which has always been looked upon as the bane of the mechanic. Now, the same may be stated with regard to the chain belt. It is capable of giving excellent results, but in order to obtain them a special form of chain must be used, and the secret of the success which Mr. Van Depoele has achieved in this country is due largely to the special form of chain which he has used. The connecting piece between the links has a thimble around it which acts as a roller, so that instead of having a frictional action on a toothed wheel it has more of a rolling action, and by taking care to keep the chain properly lubricated, not only is the noise greatly reduced, but the loss from friction is also very largely diminished.

MR. RECKENZAUN: I think there is only one point which requires observation on my part, and that is in regard to running down hill with worm gearing. I make the angle of this thread so that the car runs down hill very easily if we once start the worm. You can with your hands turn the worm wheel around almost at any speed you like, and I know from experience that a car which is provided with worm gearing will run down an incline of one in seventy to one in a hundred—it depends on the roughness of the track—very easily. If it were not for that, if the pitch or the angle of the worm thread were not sufficiently great there would be more danger, even in the case of running on the level road, than running down hill, because as soon as you cut off the current from the motor the momentum of the car would strip off all the teeth of the wheel. If you make that angle sufficiently large you will find there is no trouble at all with reference to that point which Mr. Mailloux has pointed out. If you take the formula which I have given on the blackboard, and which I suppose will be published some day, and if you take the dimensions I have put down, you will find the exact angle of the worm thread, and you will find that its angle of repose is so low that the worm wheel is bound to revolve with the greatest of ease.

As regards spur gearing, I have pointed out in the course of my observations in the paper, that I have been very well satisfied, in fact, astonished with the ease with which that spur gear which we use in Philadelphia is working.

As regards chain gearing, I have been rather unfortunate with chains, but if I had employed such appliances as Mr. Mailloux or Mr. Van Depoele, no doubt I might have been more successful. Of course Mr. Van Depoele uses rollers, and we know that rolling friction is much easier than what I call grinding friction, where the links of the chain have to grind over the teeth.

I agree with Mr. Mailloux that there will be a great competition between the different forms of gearing, and it is only that form of gearing which lasts longest and gives the least trouble which will be eventually adopted generally. But at the present time we are still in the dark as to the best form. Everyone believes his own the best because he has had the greatest experience with his own form. Any discussion of the description we have had to-night will greatly advance the subject.

MR. WHEELER: I want to ask Mr. Reckenzaun how the gear was connected to the motor. If the motor was mounted directly on the worm shaft, did not the jarring of the car shake the motor up a good deal, and prevent the brushes resting on the commutator? I do not think he has explained that.

MR. RECKENZAUN: No, sir, I have not explained that. The worm and its coupling are generally forged in one piece. I employ a slightly flexible coupling between the motor shaft and the worm shaft, and between the bearings are springs, which take off the jarring from the bed of the motor. There is very little jarring going on—comparatively little—and we have never had any trouble with the jumping off of the brushes from the commutator. If the springs on the commutator brushes are sufficiently strong there will be no trouble. In some cases I have tried—taking the brushes of the commutator to be almost horizontal—I have tried putting a balance on, so that the jarring, instead of jarring it off, jars it on, and puts pressure upon it. I found at last there is no necessity for that. There is very little trouble in that respect if it is properly adjusted in the first place. With this flexible coupling in the first place, and the wheel flexible to the bearings that support the frame of the commutator, you will find very little trouble on the points Mr. Wheeler has mentioned.

MR. WHEELER: If that motor jars up and down at all it either must twist on the foundation or else there would be a fault in the shaft.

MR. RECKENZAUN: Yes, there will be a slight fault in the shaft; but if there is a flexible coupling between, it will compensate for that. Of course we do not expect it will be half an inch out at any time, but it will allow a variation of an eighth of an inch.

MR. WHEELER: That ought to do it.

MR. MAILLOUX: I would like to call attention to a point which I put down as the first on my list, but which, in my anxiety to get through, I omitted. I do not wish to see it passed by, because I think it is of some importance, and perhaps throws light on these discrepancies relative to the efficiency of the worm which have been observed in the results of the best experimenters. I have reference to end-thrust in the motor. My own study of the theory and practice of the worm wheel has convinced me that at least a large proportion of the waste of energy due to friction in worm gearing must have been due to end-thrust. Now the question arises, did not Mr. Reckenzaun, perhaps, employ means by which this end-thrust could be reduced, if not eliminated, and in that way obtain a much better efficiency than the others who had preceded him? I wanted to mention particularly that in analyzing the experiments made by Messrs. Sellers, I was not satisfied with the precautions that they seemed to have taken to eliminate that end-thrust, and perhaps that may have been the cause of considerable loss of energy by friction.

Now there is another point which occurs to me, and which I will beg the privilege to discuss while I am up. The problem of electrical traction involves a very important requirement in the matter of securing adhesion between the rails and the wheels in climbing up grades, going around curves, etc. The electric motor has not been found successful in enabling us to climb grades higher than six per cent., or at the outside seven per cent. I have succeeded in going up a grade of six per cent. with a motor car having another car attached to it. But these are *tours de force*, so to speak, which perhaps we would not care to repeat every day. Then if we admit the necessity for a certain amount of traction—adhesion between the motor and the rails—we arrive at the consideration of the importance of having the power transmitted to both axles. In a great many cases I have found by experience that the transmission of the motion to one axle was insufficient in certain kinds of weather, when the tracks were not in the right condition. There would be a very severe and annoying amount of slipping, which would greatly interfere with the progress of the car and the success of the experiment.

Now another requirement which has presented itself in my study of the problem is this—the difficulty of starting easily, smoothly, and without hesitation, so to speak. That is a more important item of the problem than people generally imagine, and I have in mind several systems of electrical traction which are

successful in almost every respect but that. They start with a certain jump which is likely to strain, if not to rupture, some part of the mechanism of transmission, and in connection with this it has suggested itself to my mind as being an eminently desirable end to attain, to have means by which the motor could be started independently of the car. As you know, there is a certain amount of energy to overcome in the motor itself, and a certain amount of energy must be expended in giving it the velocity at which it is to be run. Now if we could do that first and not have to do it at once, or simultaneously with the overcoming of the inertia of the car itself, you will see that we will have made some gain. It would be very much like dividing a load into two portions, instead of having to lift it all at once—lifting a small part of it and then going on to lift the rest. That suggests itself to me as a very important question, and I believe that the successful system will be one in which that feature is present. I would like to hear the opinion of Mr. Reckenzaun.

MR. RECKENZAUN: With regard to eliminating the end-thrust of the motor in the case of worm gearing, I use no special precautions whatever, excepting that I employ several thrust collars. I believe Mr. John Pendleton has a system of worm gearing in which the thrust is eliminated by having two worms, one right-handed and the other a left-handed worm, so that the thrust of the one counteracts the thrust of the other. But it has this little disadvantage, that the gearing comes very near to the ground. There are two worm wheels and the motor shaft is at a tangent to the two wheels. The motor is between the two worms. By this means, the two driving wheels have to revolve in the same direction. The two worms revolve in the same direction, and being right and left-handed, the thrust is entirely eliminated. I have made one kind of worm gearing, for a special purpose, where two worms were attached to a motor which drove two worm wheels, and on the same shaft with the worm wheels were two large spur wheels, which were used for climbing up a rack. In this case, also, the thrust was eliminated, so that there was only the friction of the thread of the worm, and the worm wheel teeth.

With regard to the problem of adhesion, it is perfectly natural that the more driving wheels you have, the better will be your adhesion, because each wheel will have the same effect in assisting to start the car. I never use less than four driving wheels on my cars. I would use six if it was convenient.

MR. MAILLOUX: How do you connect them?

MR. RECKENZAUN: I use two small trucks as pivots, on one of

which the car body is supported. The car has two motors. There are four driving wheels and two driving axles. By extending the shaft we could have a second worm wheel; but that would complicate matters very much unless it was absolutely necessary for very steep grades.

It is nonsense to attempt to run cars on a grade of more than six per cent. in wet weather. It is impossible. No electric car or steam car, or any self-propelled vehicle will climb grades of more than six per cent. in slippery weather with absolute certainty. If we go beyond six per cent., we must have some artificial adhesion; we must introduce some rack on the road, or cables, which have a positive motion. Any one who attempts to guarantee a self-propelled vehicle, whether propelled by steam or any other means on grades of more than seven per cent., will most certainly lose his reputation.

With reference to starting, I have always found that electric cars start with remarkable facility; that is to say, with remarkable quietness. There is very little jerk. Mr. Mailloux mentions that most electric cars start with a jerk. I know that steam cars, cable cars and horse cars start with a jerk, but I have very seldom found it on electric cars, and I have had the privilege of riding on a good many electric cars in various parts of the world. There is a gentleman here, Mr. Stein, who I think might give an opinion on that subject. He has been on our car in Philadelphia, and I think he would assure you that it starts easily. You can hardly feel the starting; it starts gradually, and that is perfecly natural. When the current is transmitted to the motor the motor has no counter-electromotive force. Therefore the whole of the current that goes through is due to the actual wire resistance of the motor. As soon as the motor is started, as soon as the armature revolves, the current decreases immediately in proportion to the relative speed of the armature. As the counter-electromotive force is created in the armature by its revolution, so the current is reduced, and it is almost impossible to start an electric car suddenly with a great jerk. I think those are the main points Mr. Mailloux touched upon.

Mr. J. M. Pendleton: In regard to the electrical propulsion of cars, while the first efforts were being made in Paris by Mr. Philipart, in the celebrated omnibus feat, with which he paralyzed the residents of Paris by the exhibitions made on the Boulevard and also the run from Paris to Versailles and return, my attention was drawn to the question of power contained in the accumulator for the purpose of car populsion, and while an examination of that

apparatus failed to satisfy me as to its being a mechanical arrangement affording the best efficiency, yet the results attained in that demonstration convinced me that the value of the accumulator and motor will find a better application in the replacing of horses than of anything else, and as I was devoting my attention to experiments with the accumulator during those years, I gave a good deal of study to improving the mechanical devices then adopted, which were simply the connection of a D2 Siemens dynamo with the countershaft, and from the countershaft to the wheels of the omnibus, which was borrowed for the purpose, and my recollection is that the apparatus weighed about nine tons. We are all familiar with the demonstration made, and a good many are familiar with the devices used, but when I made the attempt to find something better it appeared that, according to the experience of car men, and in the opinion of those who had employed various devices with compressed air or steam, it was a very difficult subject. Our oldest car builders in conversation told me that the experiments had so far demonstrated that horses were the best things to put on cars and nothing else would do; that engines would not stand the pounding of the rail. They were very rapidly destroyed. Occasionally some invention would run smoothly for awhile, but that inevitably it came to grief in a very short peroid. Notwithstanding this discouragement, various devices such as have been spoken of to-night were reviewed one after the other, and the device which Mr. Reckenzaun has alluded to was the final result, after discarding some dozen or more, and in his sketch to-night the principle was correctly shown. But the necessity of using the worm and worm wheel running in oil was very evident to my mind. It may be remembered by a good many here that in May, 1886, I exhibited at the New York Electrical Society a design for this system of car traction, having eliminated from it all the objectionable features that could be well done on paper. I exhibited it for the purpose of getting the opinion of those who were engaged with me in investigating mechanical and electrical questions. I was discouraged afterwards by the opinions of many—some of whom are here present—as to the efficiency of the worm and the worm wheel, and it is with the greatest pleasure that I hear so well defined and so thoroughly proved by practical experiments what I may say was a chance choice, more than a scientific attainment on my part. It came to me intuitively, as it were; it seemed to satisfy me better than any other. I have had the apparatus in model for a good many months past, but other engagements have prevented my doing as much work in that line as I wished. The interest

has increased from week to week. It is only a fortnight ago that I visited Philadelphia and had the opportunity of riding upon a car which Mr. Reckenzaun had in charge at the corner of Washington avenue and Twenty-fourth street. I saw there a car under thorough control, mounting grades of five feet in one hundred feet easily, stopping in the center of the grade and starting without any difficulty. The starting from a dead stop was with ease—much more readily than we would experience in a horse car; and although I had been so many years a believer and exponent of electric traction, and particularly of accumulator traction for street cars, I will state to you that I was surprised and gratified at the practical demonstration of its value that I saw. The car was run by a motor attached to only one pair of wheels. It had always been a great doubt with me whether on grades of five to the hundred, or four to the hundred, that a car would have sufficient bite upon the rail to enable it to mount. I saw the car stop on a grade, start on a grade without any slip, and go over it, and I felt that a very important question was solved by the manner in which it performed its work. Gentlemen, there is no more doubt in my mind to-day in regard to electrical propulsion by accumulators replacing horses than that I am standing here. After the demonstrations that have been made, it is only a matter of a few months when we will find one or two lines of horse cars adopting electrical propulsion, and then you may expect it to come like the roll of the sea. There will be no supplying the demand that will arise for electrical cars. I had the pleasure that day I was in Philadelphia of being associated with two presidents of horse railways who were witnessing these experiments, and they both expressed their surprise and delight at the manner the car behaved, and at the thorough control which it was under. We have only but a brief period to wait before we will find the advantages which the adoption of a new and better system will give to the general public, and to the welfare of our cities.

THE PRESIDENT: There is one branch of the subject which has not been touched upon this evening, yet it merits our attention. We have so far confined the discussion to street cars, whereas this whole discussion might refer more largely to electrical cars in general. It may not be within your knowledge generally that within the last month or two an electrical road—the largest of the kind in this country—has been put in operation in the coal mines of Pennsylvania. We have with us this evening Mr. Schlesinger, who has put that road in operation and who has it in successful operation to-day. He there handles trains of a hundred tons

weight, and his experience in dealing with the particular question that was touched upon, of moving off easily and quickly, without any jarring of the machinery, would be very valuable in this connection. I think it would afford us all a good deal of pleasure to hear of his experience in the Lykens Valley coal mines.

MR. SCHLESINGER: In the Lykens Valley coal mines we enter into competition with one or two lines of horses and also with the steam engine. The mules were taken off entirely the second day, and I think that the steam engine has also seen its last days in the coal mines. It is proposed wherever steam locomotives are being used to change them for electric motors in a very short period. The trains we have to handle are sometimes as large as 100 tons. We have to take them over grades of about one per cent. to two per cent. and around 90 degree curves, one of them being 25 feet radius. We are obliged to start trains on these curves. The mode of transmitting the power from the motor to the wheel is chain-gearing. I found that wherever the train stands, the starting is very easy, or would be very easy if it were not for the fact that the cars are generally bumped together, and the load is not all put at once on the motor, but gradually. One car starts after the other, and this is an objectionable feature so far as the easy starting is concerned. If the whole train started as one, then it would move off very nicely and easily, without any jar at all, and that is another reason why I think it is always preferable to have the motor geared in such a manner to the car, that both start together, not the motor first, and then the car; there will always be a jar if this is not the case. It is the same thing as if the chain gearing should have stretched. It will always be noticeable that the car starts far more heavily, and with a greater jerk, than if the chains are perfectly tight. Outside of that the weight and power required to stop the motor are so small, as compared with the power required to start the whole thing, that there is very little gained in starting one, especially the motor, before the other. The chains we are using in the Lykens Valley coal mines are the same Mr. Van Depoele is using, and side by side with that we use a chain which I have specially constructed for the purpose. The links are made of phosphor-bronze and the pins are of steel. The chain with a thimble is not giving much satisfaction up there. I suppose it is because of the very heavy strain upon it.

CAPTAIN O. E. MICHAELIS: A remark that Mr. Schlesinger has just made in regard to the increased shock due to the successive movement of the cars constituting the train brings to my mind a remark that the reader of the evening also made in his paper, which

I saw was clearly founded on experiments, and not simply the result of theory. That remark was that the duty upon the motor was greater in starting the train than afterwards, and Mr. Mailloux continued somewhat in the same manner. Now, during the present year there was a series of remarkable experiments made at Burlington under the auspices of the Master Car Builders' Association, which will bring about, I think, an entire revolution in the method of connecting trains, and I am fain to confess that these experiments appear to upset all our preconceived theories as to the duty of the motor in starting trains. I speak on the subject because I am at present engaged on this coupler question, and therefore take some interest in it. These experiments showed that the greatest duty upon the locomotive in this case was actually after the whole train had been started, and it is very curious. I am willing to admit that I was entirely mistaken myself, because at the very time, almost, of my receiving the account of these experiments, I had taken great pains to explain to a friend of mine the theory by which a train was moved by the successive picking up of the cars—a theory which was of course upset by these experiments. The result of that has been that the Coupler Committee of the Master Car Builders' Association—all prominent railroad men in active practice—unanimously agreed at the convention in Minneapolis that the future coupling of cars shall be tight and not loose, and have recommended the abolition of the pin and link coupler and the substitution of a close vertical hook, which I think coincides with what Mr. Schlesinger has said.

MR. MAILLOUX: I stated that one of the difficulties was the sudden starting of electric cars. Now I should have said that circumstances were responsible for that. It depends very much on the way in which the energy is given to the car; and when you are dealing with accumulators it is not often possible to apply the electrical current to the car in a manner sufficiently gradual and slow to prevent that sudden onslaught of motion, so to speak. That is what I had in mind in speaking of the sudden motion. If the current is supplied over circuits with devices by which it can be put on more slowly or more rapidly, according to circumstances, the case is different; but with storage batteries generally, it is far more convenient to have as few combinations as little mechanism as possible in the regulating apparatus, so as to not complicate things. Now, with regard to the starting of the motor shaft first, the opinion I expressed was the result of experiments. I have seen the virtue and the value of that point demonstrated quite recently by means of a system in which the motor is started first,

giving free scope to the full electromotive force of the battery and allowing it to run at a very high speed, and accumulate energy in the form of momentum, so that not only that part of the work has been done, but we have even stored a certain amount of energy there, which, when a device is applied, shall enable us to make use of that storage energy to start the car itself. I have seen the results demonstrated by a gentleman who has a system of traction, and I must say that it struck me very favorably indeed. He used a frictional device in the connection between the motor and the other, also combined with spur gearing; but when I saw the ease with which he started and stopped, and overcame grades, etc., I was convinced that there must be something in it. I still believe it.

MR. PENDLETON: I called Mr. Mailloux's attention to the value of the electric motor, particularly for the purposes for which we are applying it, and that is that the electric engine has its greatest traction at the time of starting, and was therefore more particularly valuable for the purposes of car traction than any other engine we know of, and in order to get this momentum of a small armature for the purpose of moving a heavy car, it would only invariably bring about the result of a jerk, which we have none of us noticed, so far, in the actual tests and experiments made. I have failed to see it. I have noticed particularly in regard to the cable cars that it is very disagreeable, for obvious reasons, but where we are using a ten horse-power motor weighing seven hundred or eight hundred pounds, for the purpose, and the armature of which is but a fraction of the weight, the momentum there can amount to very little in a car weighing six tons, and I doubt whether any continued observation on his part—a man of such experience and intelligence—would bring about the support of his theory.

MR. MAILLOUX: I must repeat what I know to be facts. They are not mere theories or chimeras, but they are facts. Now, if you stop to reason for a little while you will readily see that when a motor is allowed to run very fast its counter electromotive force approximates very closely to its source of energy. Consequently the current through it is very small. If you put a force like a brake that tends to slacken that motor and gradually couple it with the driving axle, you will have a variable velocity ratio between the two, which ratio is gradually approaching unity. As you put on a greater and greater effort you are slacking the motion of the armature and getting the benefit of its momentum, while at the same time the current is increasing through it, and in that way you have the most gradual putting on

of the current that you can hope for. I have seen the experiment made so many times that I for my part do not doubt it any more.

THE PRESIDENT: There being no further discussion, I will simply ask Mr. Reckenzaun to make one or two closing remarks.

MR. RECKENZAUN: I was merely going to reply to Mr. Mailloux. On the very first car which I constructed in 1882, which was worked by storage batteries, I used the momentum not only of the armature of the motor, but also the momentum of a fly-wheel, which weighed between three and four hundred weight. I put the fly-wheel upon the countershaft, and I used that gearing which I sketched on the board to-night—that peculiar gearing with the disks and a wedge shaped band. I employed the friction clutch. I thought that by starting the motor to its full speed, and with a heavy fly-wheel, that that would be a great advantage in the starting of the car, but I was greatly disappointed. The car started with a jerk, and when I did away with the fly-wheel I found that the car started with the greatest of ease, and I believe from actual experience which I have had in this direction, that it is far better to start without the momentum of the armature or the momentum of any substance connected with the armature. It is perfectly natural that an electric motor must start gradually. Take the motor off the car altogether and put it upon a table and send through it any current from any battery you like, or from any source of energy you like—fifty volts, one hundred volts, or five hundred volts—and you will find that the armature cannot start suddenly. It requires a few seconds to take up its speed, and therefore it is perfectly natural that a car propelled by electric energy must start gradually. It is a perfectly natural consequence.

Our worthy president has requested me to make some concluding remarks, but the hour is late, and I believe gentlemen will be very glad to get off. I have nothing more to say. I have been exceedingly interested in the various remarks which have been made to-night, and I must own that I have learned a great deal. With regard to the general application of electricity to street car propulsion, as Mr. Pendleton has pointed out very forcibly, there is a very great future in store for us, and the time is very near when horses on street cars will be entirely abandoned. We have, I might say, almost passed the experimental stage and we are now entering the more profitable stage of manufacturing and supplying street railways with electric motors. The advantages in electric motors are not only economy, but cleanliness and great saving of space at the depots and great saving of space on the streets. If you take crowded streets like Broadway, New York,

and many other thoroughfares where every square inch of space you might save in the street is of value, if you do away with horses you save in length about twelve feet, and in width, of course the width of the track. Now, it would seem ridiculous for me to make such a remark, but if there are hundreds of cars running in a crowded street it makes many thousand square feet of space saved, and in that space other vehicles can pass. Another great advantage in electrical propulsion will be (apart from economy which is certain to be a result) that we shall be able to travel at a greater speed. Horses cannot pull a car at a greater speed than six miles an hour. The average speed of all the horse cars in America and Europe is five miles an hour, including stoppages. Now, if we can travel at the rate of eight or ten miles an hour a great deal of time will be saved and passengers will avail themselves more of the new mode of traction. They will save a great deal of time. The traffic is constantly increasing. I have heard recently that the street car traffic of New York alone has increased in the last ten years fifty per cent. If it increases in the next ten years fifty per cent. again it would be impossible to cope with the traffic if we employ horses at all. The elevated railroads, it appears, are doing a large amount of business—almost as much as they are capable of handling, and the only loophole, it seems to me, out of the difficulty, is either by building underground railways or by propelling the street cars at a greater speed, so that the same number of cars will carry double the number of passengers in the same time. With these remarks, gentlemen, I close, and I thank you very much for your very kind attention. (Applause).

MR. WHEELER: I move a vote of thanks to Mr. Reckenzaun for his interesting and instructive paper.

The motion was seconded by Mr. Wetzler, and carried.

MR. MAILLOUX: If I may be allowed to express another thought I would like to say that I wish we also had a medal, that we might be able to give it to Mr. Reckenzaun, because in the discussion of the subject that he has brought before us this evening, I for one, and doubtless a great many others who are here—particularly those of us who are especially interested in the subject—feel that we have been dealing with the work of a master—a man who is eminent in his work and from whom we can all learn deep and valuable lessons. That is the reason, gentlemen, why I feel that we also ought to have given Mr. Reckenzaun a medal or some other substantial recognition of the valuable work that he has placed before us.

Mr. James D. Reid: I am not able to express myself in scientific terms, but I think our good friend here has struck a strong feature of human nature, which convinces me that he has also struck the right vein in science. We all know that human life is a life of friction, that life is a struggle all the way through, even with the help of the best of food and the best of wine and the best of Scotch whisky. It is a struggle after all, and, gentlemen, I appeal to you, if, after life has done its best, the worm does not triumph in the end. (Laughter and applause).

The meeting then adjourned.